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LEAN SPACECRAFT AVIONICS TRADE STUDY

Prepared By:	John A. Main, Ph.D.
Academic Rank:	Research Assistant Professor
Institution and Department:	Vanderbilt University Department of Mechanical Engineering
NASA/MSFC:	
Laboratory:	Preliminary Design
Division:	Systems Engineering
Branch:	Systems Analysis
MSFC Colleague:	Melody Herrmann

BACKGROUND

Spacecraft design is generally an exercise in design trade-offs: fuel vs. weight, power vs. solar cell area, radiation exposure vs. shield weight, etc. Proper analysis of these trades is critical in the development of lightweight, efficient, "lean" satellites. The modification of the launch plans for the Magnetosphere Imager (MI) to a Taurus launcher from the much more powerful Delta has forced a reduction in spacecraft weight availability into the mission orbit from 1300 kg to less than 500 kg. With weight now a driving factor it is imperative that the satellite design be extremely efficient and lean. The accuracy of engineering trades now takes on an added importance.

In some cases the balance between design utility and design "cost" are clear. For example, given the choice for a satellite stabilization system between an active gas jet system or a passive mass-spring-damper system, the passive system is clearly the choice in terms of cost and reliability if it can provide the necessary performance. Less clear are the trades involved in the avionics requirements for a given satellite, particularly when the avionics in question interface with the payload instruments. Optimal requirements for instrument avionics are difficult to define because they generally involve interactions between electrical systems (computers, instruments, power supplies, guidance and control electronics, etc.), mechanical systems (instruments, guidance and control hardware, mass balance systems, etc.), and information (software, telemetry data, instrument data, instrument controller commands).

An understanding of spacecraft subsystem interactions is critical in the development of a good spacecraft design, yet it is a challenge to define these interactions while the design is immature. This is currently an issue in the development of the preliminary design of the Magnetosphere Imager (MI). The interaction and interfaces between this spacecraft and the instruments it carries are currently unclear since the mission instruments are still under development. It is imperative, however, to define these interfaces so that avionics requirements ideally suited to the mission's needs can be determined.

PROJECTED INSTRUMENT PAYLOAD

The proposed MI payload consists of three instruments: (1) the Far Ultraviolet Imager (FUV), (2) the Plasmasphere Imager, and (3) the Hot Plasma Imager. Exact instrument interfaces are impossible to define at this point of the design process, but some general ideas of payload requirements can be gleaned from examining the heritage of the payload instruments.

Wilson (1993) compiled an extensive report on the development history of the MI instruments. This report was used in addition to conversations with members of the Magnetosphere Imager Science Definition Team (SDT) to gain a better understanding of the functional requirements of the payload instruments. The results of this effort are embodied in the bullets in the following sections.

Far Ultraviolet Imager

- Essentially a monochromatic telescope (photon counter)
- Requires a filter wheel and associated motor to move the wheel to look at different wavelengths
- Image may be swept across a CCD as the spacecraft rotates, or the instrument may use a periscope to stare at one point in the sky

- SDT data rates 7 kbs
- SDT pointing accuracy 0.5 deg

Hot Plasma Imager - High and Low Energy

- Essentially an event counter, used to look at various q/m ratio particles
- Instrument will require specification of spin rate from the spacecraft (or ground operator)
- Unusual in that it requires a controllable high voltage power supply
- Goal is to produce 1 image per minute
- No moving parts
- Commands that may be uploaded include changes in image integration time, compression schemes, ON/OFF cycling, instrument status checks, uploading code to instruments, performing passive telemetry on instrument, change in high voltage level, temperature data, etc.
- SDT specified FOV - 4π str
- SDT dimensions High Energy .51x.35x.51 m
 Low Energy .30x.30x.25 m
 electronics .30x.30x.30 m
- SDT masses High Energy 14 kg
 Low Energy 7 kg
 electronics 8 kg
- SDT power High Energy 4 W
 Low Energy 7 W
 electronics 12 W
- SDT data rates High Energy 12 kbs
 Low Energy 6 kbs
- SDT pointing accuracy 5 deg

THE MI INSTRUMENT-AVIONICS INTERFACE

The challenge in defining the instrument interface to the MI avionics system is centered around the fact that the satellite instruments are still undefined at this point. There are ways to address this problem, however. What we can do is define two interfaces, basically a worst-case and a best-case. These two options are chosen with knowledge of only the most basic facts about the instruments such as weight, power, field of view, and instrument heritage. With such limited knowledge it is difficult to explicitly design the interface, or controller, so the goal is to define with these two designs the spectrum of possibilities in which the final instrument control system will fall. We can do this with confidence because the requirements and specifications in the previous section do not

specify any instrument characteristics that are unusual enough to drastically impact the controller design.

Option 1-Distributed Instrument Control. The two instrument control schemes conceived for MI are illustrated in Figure 1. The first scheme to be discussed is the distributed control scheme. This design is basically the "high performance" option. The operation of each science instrument is independent in this design, with each having its own computer/controller that acts as the interface between it and the main onboard computer. The advantages of this control strategy are numerous. Distributing control to each science instrument maximizes the probability of getting at least some data from the spacecraft. It also simplifies and compartmentalizes software, saving programming time. In this same vein it allows the science instrument developers, who may be geographically distributed, development independence.

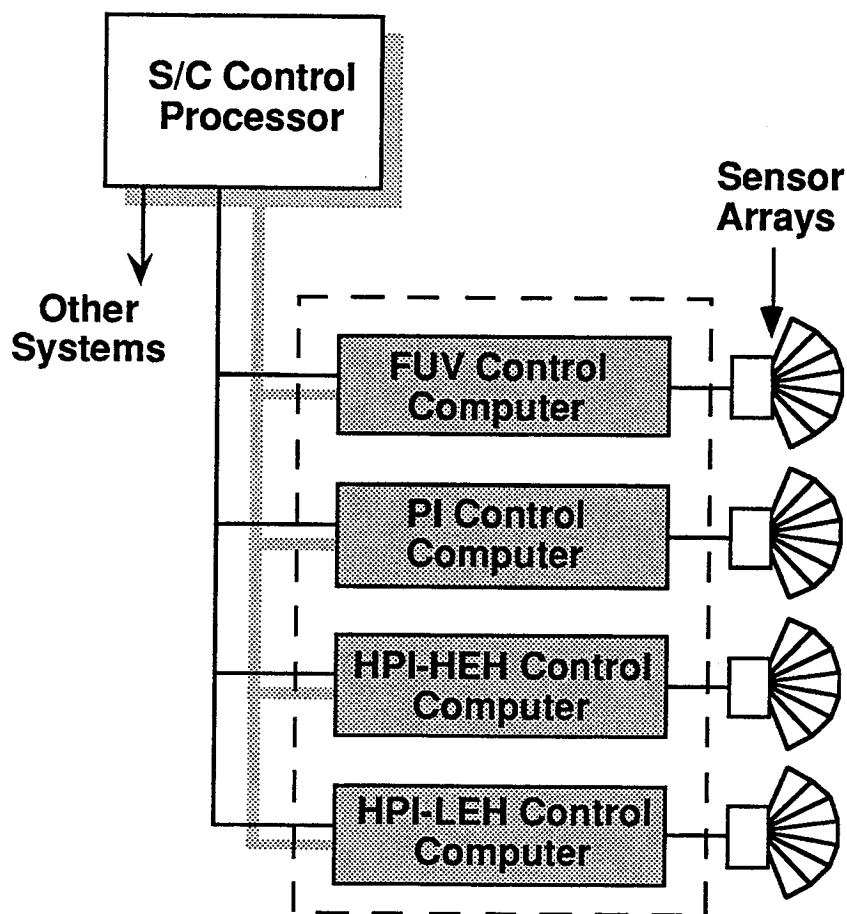


Figure 1. Sketch of the MI instrument controller options.

On the other side of the coin, distributed control has design costs that may preclude its use. Since each instrument has a dedicated and independent computer that is not available for any other tasks, the spacecraft computer may need a backup in case it fails. This means that there may be five or six computers that must be qualified for the mission. Each computer adds mass, but the overriding consideration may be the cost to space qualify all this electronic hardware. Significant savings might be achieved by combining the controllers of two or more of the instruments.

Option 2-Centralized Instrument Controller. The logical extension of combining two instrument controllers into one is to combine all the instrument controllers into one. This master controller is represented in Figure 1 by the dotted box that surrounds the four distributed control computers. This strategy results in a number of advantages, including a lower mass system, a lower power system, and the need to qualify fewer components. If the system is properly designed the master control computer and the spacecraft computer could be used as backups for each other, eliminating the need for a backup spacecraft computer. This was the control strategy used in the recent low-cost Clementine project at the Naval Research Laboratory.

Obviously there are disadvantages to this method as well. The two most important appear to be an increased complexity in the software and the necessity for significant coordination among the science instrument designers/builders.

CONCLUSIONS

A range of control possibilities are defined by the two control options presented herein. It is likely that both will prove to be impractical in some respect: option 1 may prove to be too expensive and option 2 may not provide the necessary performance. Currently in the overall MI design option 1 is baselined, but there is a risk involved here. Option 1 certainly represents a "worst case" option in terms of cost, weight, and power. For planning purposes this is a good, conservative, model. The risk comes when talks begin with the science instrument builders. If they perceive that the distributed control scheme is the baseline scheme, they will be very reluctant to give up any of their control computers to save cost and weight. If possible, the baseline control system that is presented to the instrumenters should be as close as possible to option 2. This will start the process at the low cost option and the design process can then proceed in a rational fashion. The instrumenters and spacecraft design team can add controllers when performance makes it necessary, instead of giving all instruments a control computer, potentially adding unneeded weight, capacity, and cost.

REFERENCES

Wilson, G.R., "Inner Magnetosphere Imager (IMI) Instrument Heritage", NASA Contractor Report 4498.